Desalination 284 (2012) 55–61

Contents lists available at SciVerse ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Experimental study of a novel portable solar still by utilizing the heatpipe and thermoelectric module

N. Rahbar, J.A. Esfahani *

Mechanical Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran

ARTICLE INFO

Article history:
Received 1 June 2011
Received in revised form 11 August 2011
Accepted 21 August 2011
Available online 14 September 2011

Keywords:
Portable solar still
Thermoelectric cooling
Desalination
Heatpipe

ABSTRACT

In this study, an attempt has been made to design a new type portable thermoelectric solar still (PTSS). In the PTSS, a thermoelectric module is used to improve the temperature difference between evaporating and condensing zones. Also, a heat-pipe cooling device is used to cool down the hot side of the thermoelectric cooler. To evaluate the performance of the PTSS, the equipment was tested under the climatic condition of Semnan (35° 33′ N, 53° 23′ E), Iran. The experiments were carried out in 5 days. The measurement of solar intensity, wind velocity, ambient temperature, water production, and temperature of other components, for example, thermoelectric module, water, walls and heatpipe was done in the same manner for each day. The results showed that ambient temperature and solar radiation have a direct effect on still performance but there is a reduction in water productivity by increasing the wind speed. The results also showed that temperature of thermoelectric device was lower than that of walls which indicated on the higher production of water.

1. Introduction

In the last 40 years, the problem of freshwater shortage has been one of the main challenges in the world. Potable water not only is important for life but also for industrial and agricultural purposes. Although more than 75% of the earth covered with water, only 0.014% of that can be used directly for the human being and other organisms. On the other hand, sea water constitutes 97.5% of global water, so it can be used for those purposes by converting it to distilled water [1]. There are some techniques for water purification, which among them, solar water distillations is an attractive subject. Solar energy is abundant, never lasting, pollution-free and available on-site. Solar stills are the simplest solar distillation units. They are cheap and need low maintenance but, most of them suffer from their low productivity [2]. Recently many attempts have been made either for setting up the various types (simple slope [3], weir-type [4], double slope [5]) or for increasing the performance and productivity of solar stills (using fin [6,7], double glass cooling [8], air motion inside still [9,10] and sandy heat reservoir [11]).

The solar distillation systems are mainly classified into two categories: passive and active solar still. In passive solar stills, solar radiation is the only parameter which affects on evaporation, but in active solar stills by using the additional device such as fan [10], pump [11], sun tracking system [12] or solar collectors [13–15], the temperature difference between evaporating and condensing area is increased, and consequently enhancement on productivity is achieved. Active solar stills also can use waste heat of other processes or devices to improve the evaporation rate of water. Kumar and Tiwari [16] used the thermal energy of Photovoltaic panel to heat the water and reported more than 3.5 times higher efficiency than the passive solar still.

In remote area or arid regions, accessibility to fresh water is a big problem. On the other hand in most arid regions solar intensity is high, so, solar stills can be used to solve that problem. Usually in those situations, there is a need to have a transportable solar still. There are a few investigations on the portable solar stills. Basel [17] made a transportable hemispherical solar still by using four wheels to make it transportable.

The main problem in designing a portable solar still is the reduction of size due to portability. So the received solar radiation, the size of condensing and evaporating zones and consequently the productivity and efficiency of still are decreased. In a study, the authors of the present paper used thermoelectric technology to overcome this problem [18]. In that work, it was shown that an enhancement in productivity was achieved by using the thermoelectric technology. The maximum efficiency and productivity in winter days were 13% and 1.2 L/m^2, respectively.

The thermoelectric effect was first discovered by a German physicist, Seebeck, in 1821. He observed that, in a closed circuit of two dissimilar metals, when the two junctions were maintained at different temperatures, an electric current is produced. In 1834, Jean Peltier, discovered a reverse phenomenon to that of Seebeck. He found that there is a heating or cooling of a junction of a pair of dissimilar substance, if direct current is passed through them. In 1838, Lenz, a German scientist froze and melted a water droplet by these effects

* Corresponding author. Tel.: +98 511 8763304; fax: +98 511 8763301.
E-mail addresses: Rahbar@semnaniau.ac.ir (N. Rahbar), jaesfahani@gmail.com, Abolfazl@um.ac.ir (J.A. Esfahani).

0011-9164/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.desal.2011.08.036

which led to the concept of thermoelectric refrigeration [19]. Today, the commercial types of TECs consist of P-type and N-type blocks of semiconductor materials. When electrons pass through P-type to N-type semiconductors, cooling effect occurs.

Thermoelectric coolers (TECs) have no moving parts, so, they have a long life. They are noiseless, simple, compact in size, easy controllable, suitable for low capacity or case in which the energy cost is not the main consideration. These equipments can operate in any position, and they have no any leakage problems. TECs can efficiently work with photovoltaic panels due to the low-voltage requirement, and they can accept a power supply directly from PV panel. Because the performance of Peltier devices is almost independent of its capacity, they have definite advantages for cooling small enclosures. So many manufacturers use them for cooling cold boxes especially when the power source is 12 V. The thermoelectric devices are also insensitive to movement, so they are attractive for use in portable devices [19–21].

Effective heat removal from the hot side of a thermoelectric module is extremely important for any thermoelectric cooling device. It may possible to have a low temperature on the cold side of the thermoelectric module [22], if the rate of the heat removal from the hot side is increased. Usually a combination of fan and heat sink was used to cool down the hot side of the thermoelectric module, but to have a good heat transfer between heat sink and air flow, the surface of the heat sink is chosen much larger than the surface area of TEC modules. As a result, those fins located on the edge of the base plate are not efficient. Choosing a suitable heat sink is also difficult because there is no simple analytical solution for general finned heat sink problems and numerical methods are usually applied [23]. Some studies have been made to replace the heat sinks with the other devices and overcome this problem. Vián and Astrain [22] reported the 36.5% improvement of COP in thermoelectric refrigerators by using a combination of phase change material (PCM) and a thermosyphon cooler. In another work, they reported 66% improvement of COP by using two-phase thermosyphon instead of heat sink [24]. The same results were also reported by Riffat et al. [25].

In the present paper, by using the conclusions mentioned in the previous researches, a commercial heatpipe was used for cooling down the hot side of the thermoelectric module. The daily performance under Semnan (35° 33′ N, 53° 23′ E) climate condition was also evaluated, and life cost analysis was done to calculate the cost of water productivity.

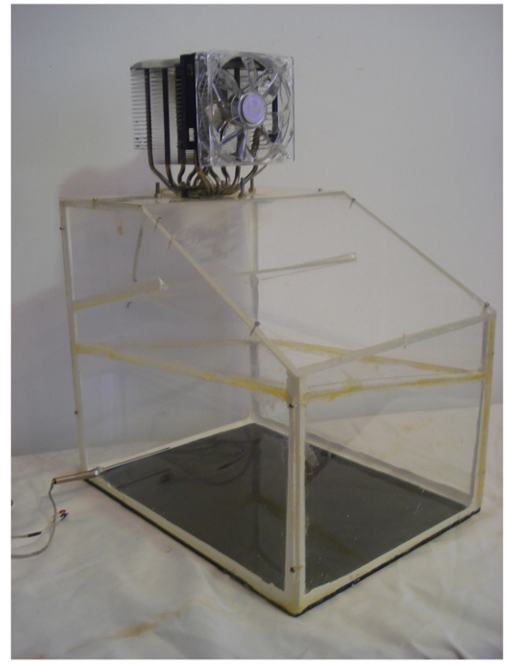

Fig. 2. Photograph of the portable thermoelectric solar still.

2. Experimental setup

Due to the portability of solar still, all walls were made of 6 mm Plexiglas. A schematic diagram and a photograph of the still are shown in Fig. 1 and Fig. 2. The bottom side of the solar still is a black Plexiglas to absorb the maximum solar radiation. The condensing zone consists of an inclined and a horizontal region. The inclined region has the same material and the same thickness as walls, and it is positioned at the

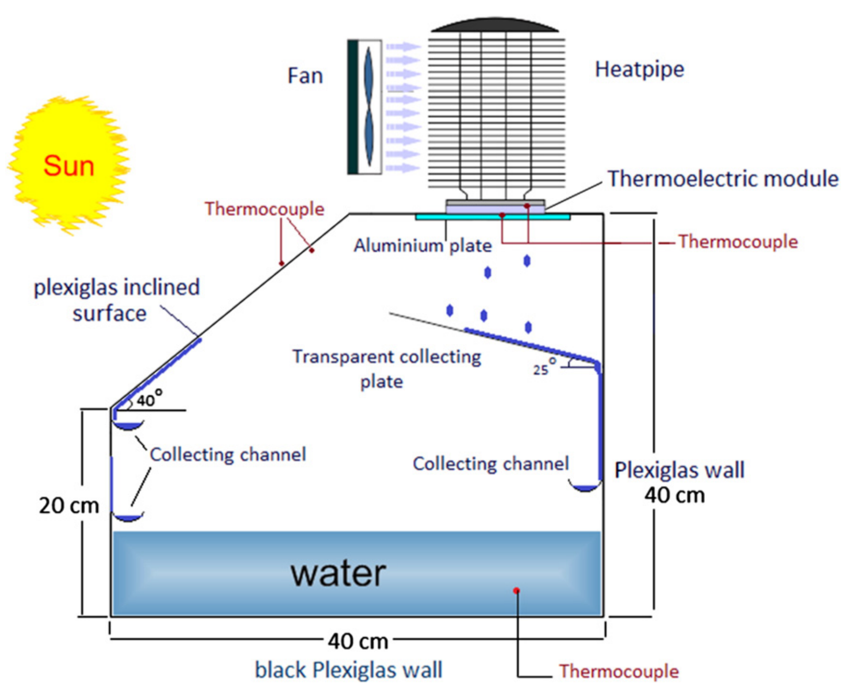

Fig. 1. A schematic diagram of the portable thermoelectric solar still.

Table 1
Accuracies, ranges and standard uncertainty of measuring instruments.

	Instrument	Accuracy	Range	Standard uncertainty
1	Kipp–Zonen solarimeter	1 w m^{-2}	0–5000 w m^{-2}	0.6 w m^{-2}
2	Anemometer	0.1 m s^{-1}	0.4–30 m s^{-1}	0.06 m s^{-1}
	Temperature (type K)	0.1 °C	−100–1300 °C	0.06 °C
3	Volume meter	0.2 mL	0–5 mL	0.115 mL

angle of 40°. In the horizontal roof region, there is an aluminum plate cooled with a thermoelectric module. The aluminum plate has 13×26 cm^2 area and thermal silicon paste was used to connect it to the cold side of the thermoelectric cooler. The condensed water collected on the aluminum plate dropped on the inclined surface and conducted to a collecting channel below the inclined surface. The collecting plate was made of transparent Plexiglas, so it may not affect on the solar intensity. Also, because, all walls are transparent and they haven't got any insulation, some other collecting channels are positioned on the vertical walls for collecting the condensed water.

The model of thermoelectric module is TEC1-12708 which is manufactured by HB Corporation. The thermoelectric cooler is also cooled with a commercial heatpipe, "CoolerMaster hyper Z600R" which is shown in Fig. 2. The size of the contacting areas between the heatpipe and the thermoelectric module is the same. The contacting areas are also covered with the thermal silicon paste to improve the rate of heat transfer between them. Also, a 1.9-Watt fan was used to cool down the heatpipe and to have the ability of working with PV-panels, a 12 V DC power source was chosen to drive the fan and thermoelectric cooler.

At the start of every experiment, the evaporating zone (which has the area of 40×30 cm^2) was filled with raw water. The bottom of the evaporating zone was made of the black-color Plexiglas to absorb the maximum solar radiation.

3. Experimental procedure

To evaluate the performance of solar still, the setup was tested under the climatic condition of Semnan (35° 33′ N, 53° 23′ E), Iran. A typical summer day and five autumn days (2 of August and 5–9 of December 2010) were chosen to collect the experimental data. The experiments were carried out every day from 9 a.m. to 4 p.m., and in all experiments the solar still is positioned toward the south. To avoid the effect of water depth on the still productivity [26–30], the volume of water at the beginning of experiments kept constant at 3 L. Also for scale preventing, the still was cleaned before every experiment. During these periods, the climatically conditions such as solar radiation, ambient temperature, wind velocity, and thermal operating conditions such as temperature of condensing area, temperature of water, temperature of two sides of thermoelectric cooler and productivity were measured. Also, the local mean daily ambient temperature and mean daily wind velocity were inquired from the Semnan meteorological station.

4. Theoretical consideration

4.1. Solar still efficiency

The ratio of the energy used for water production to the total solar radiation rate is the instantaneous efficiency of a solar still η_i, and it is given by [1]:

$$\eta_i = \frac{Q_{ev}}{HA_b} \tag{1}$$

where

$$Q_{ev} = \dot{m}_{ev} L \tag{2}$$

The solar still daily efficiency, η_d, is also calculated from the following equation [29]:

$$\eta_d = \frac{\sum Q_{ev}}{3600 \sum (HA_b)} \tag{3}$$

4.2. Life cost analysis

Economic analysis of water desalination unit is given by Fath et al. [31], Kumar and Tiwari [32] and Kabeel et al. [33]. If P is the capital cost of the system, i is the interest rate (12% in Iran) of lending banks, n is the life of the system (10 years) and CRF is the capital recovery factor, the first annual cost of the system FAC can be determined by [33,34]:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4}$$

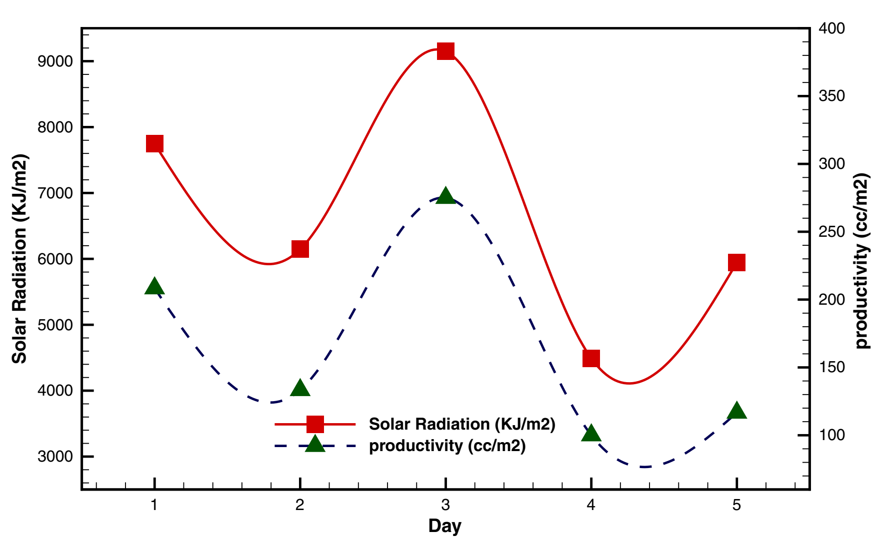

Fig. 3. Variation of daily productivity and total solar radiation during 5 days of experiments.

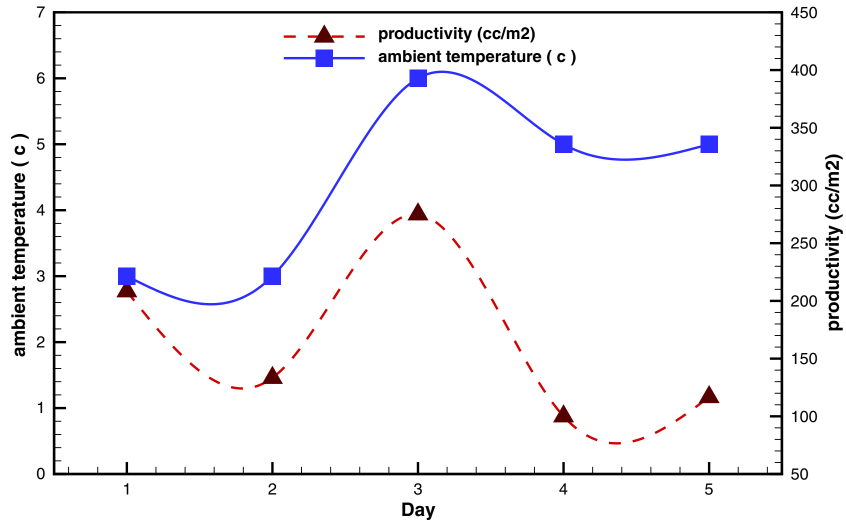

Fig. 4. Variation of ambient temperature and productivity during 5 days of experiments.

$$FAC = P(CRF) \tag{5}$$

The salvage value of the system S usually was considered as 20% of the cost of usable materials which were saved even after the life of system is over.

$$S = 0.2P \tag{6}$$

The first annual salvage value (ASV) of the system can be calculated by:

$$ASV = (SSF)S \tag{7}$$

where SSF is sinking fund factor and can be calculated by:

$$SSF = \frac{i}{(1+i)^n - 1} \tag{8}$$

Every system requires some maintenance and annual maintenance cost and AMC is considered as 15% of FAC:

$$AMC = 0.15(FAC) \tag{9}$$

The total annual cost of the system can be calculated by:

$$AC = FAC + AMC - ASV \tag{10}$$

Finally if M is the average annual productivity, the cost per liter (CPL) of the water production can be determined by:

$$CPL = \frac{AC}{M} \tag{11}$$

4.3. Uncertainty analyses

In this research, all measurands are supposed to be distributed uniformly and so their uncertainty is of the Type B. In this case the standard uncertainty is expressed as [35,36]:

$$u = {}^{a}\big/_{\sqrt{3}} \tag{12}$$

The uncertainties associated with the experimental facilities are shown in Table 1.

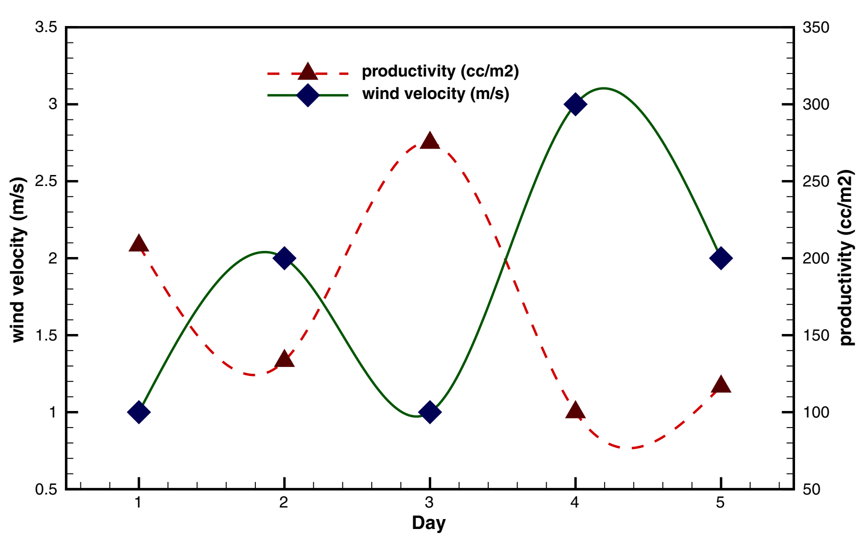

Fig. 5. Variation of wind velocity and productivity during 5 days of experiments.

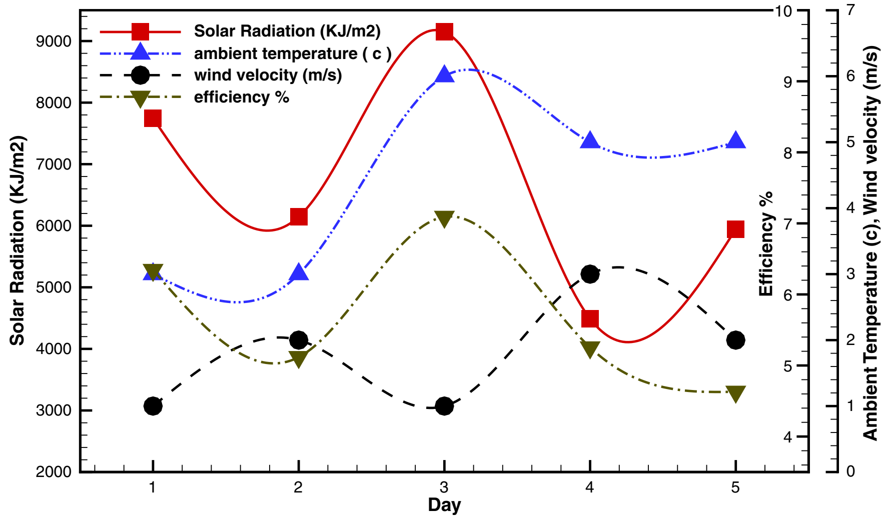

Fig. 6. The daily efficiency versus climatic conditions during the period of experiments.

When y depends on an arbitrary number of input quantities x_i, then the uncertainty of y is calculated by [35,37]:

$$u(y) = \left[\left(\frac{\partial y}{\partial x_1}\right)^2 u^2(x_1) + \left(\frac{\partial y}{\partial x_2}\right)^2 u^2(x_2) + \ldots\right]^{\frac{1}{2}} \tag{13}$$

Therefore the uncertainty for daily efficiency can be calculated by:

$$u(\eta) = \eta\left[\frac{u(\dot{m})^2}{\dot{m}^2} + \frac{u(I_s)^2}{I_s{}^2}\right]^{1/2} \tag{14}$$

The maximum uncertainty for daily efficiency calculated from Eq. (14) is 0.04%.

5. Results and discussion

Climate conditions can affect on the still productivity [38]. Fig. 3 shows the daily productivity and daily solar radiation during 5 days between 5 and 9 of December 2010. It is concluded that productivity of the still is directly proportional to daily solar radiation. Fig. 4 and Fig. 5 show the effect of mean daily ambient temperature and mean daily wind velocity on the still productivity. It was concluded that when the ambient temperature increases, the productivity is also increased, but the wind velocity has an inverse effect on the still productivity. Increasing in wind velocity, increases the rate of heat transfer and this lowers the temperature of water [18]. In the fourth day and the fifth day, there is a high ambient temperature but, due to the low solar intensity, the productivity decreased. At the other hand, in a high ambient temperature the cooling effect of the heat-pipe is decreased, and this is another result of the low productivity.

Fig. 6 shows the variation of daily efficiency calculated from Eq. (3), daily solar radiation, mean daily wind velocity and mean daily ambient temperature. Except the last day, the trend of daily efficiency was directly similar to the trend of solar intensity and ambient temperature. In the last day, the productivity remained constant, but due to increasing solar intensity, the efficiency decreased.

Fig. 7 shows the temperature variation of the still components during the last day of experiments. It is seen that the temperature of thermoelectric cold surface was lower than that of the inclined

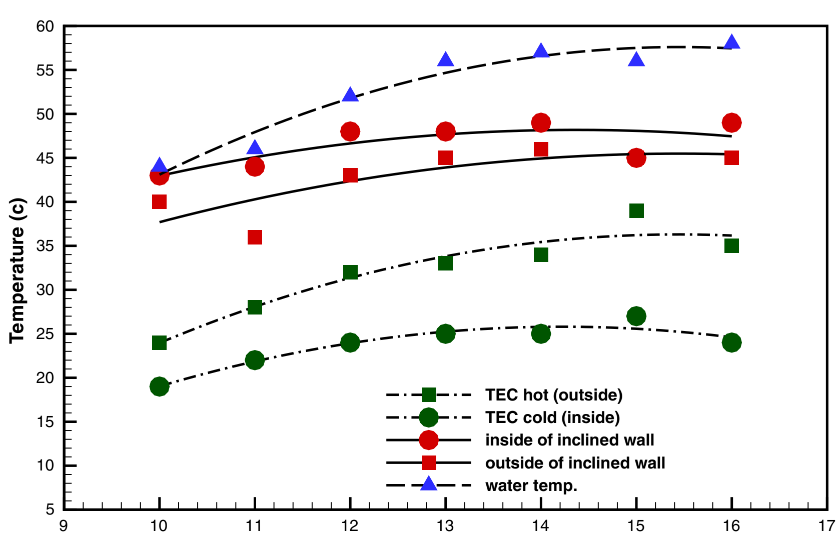

Fig. 7. Temperature variation of the still components.

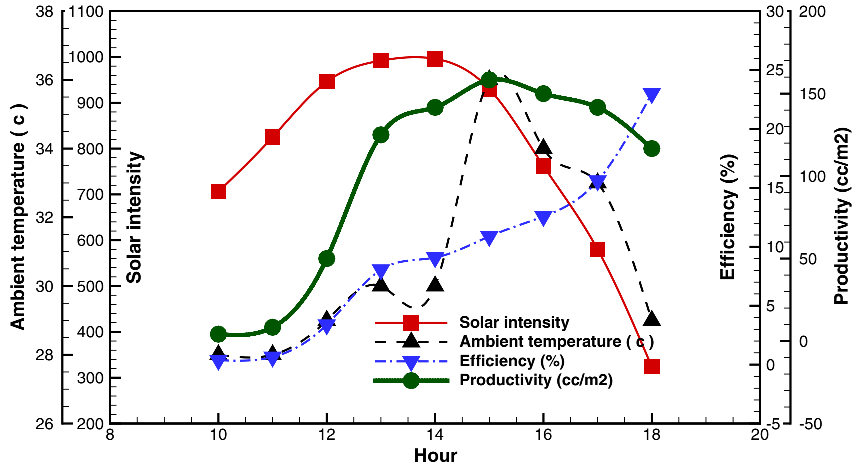

Fig. 8. The hourly variation of climatic conditions and instantaneous efficiency in a typical day (8/2/2010).

wall. Because increasing of the temperature difference between the water and the condensing area leads to a better efficiency and better production [13], it can be concluded that by using the combination of heatpipe and thermoelectric module it is possible to increase the productivity of the still. The maximum temperature difference between water-wall and between water-thermoelectric was 9 °C and 34 °C, respectively.

At the beginning of the day, there is a small temperature difference between the water and inclined wall, so no distillations on the inclined surface were happened. However from Fig. 7 it is concluded that there is always a high-temperature difference between water and thermoelectric cooler (about 28 °C). So even at the beginning of experiments it can be possible to have the water productivity. The temperatures of inside and outside of the inclined wall are also shown in Fig. 7. It was found that, there is a temperature difference between the inside and the outside of the condensing area which is consistent with the results of literature [29,39]. Another result of Fig. 7 is the temperature difference between the outside of thermoelectric module and the outside of inclined wall. This is because of the existence of force convection produced by the fan of heatpipe. Fig. 8 shows the hourly variation of radiation, ambient temperature, productivity and instantaneous efficiency in a typical day (8/2/1020). It can be observed that the instantaneous efficiency increases with time. After 4 p.m., there is a sudden increasing in the efficiency. This is because of decreasing in solar intensity while the productivity remains constant due to heat capacity of water and the reduction of ambient temperature.

6. Cost analysis

Typically in designing a solar still, maintaining the lowest cost is the main object. Cost estimation for different components used in the present work is given in Table 2. The cost of production was about 181$. The main parts of the cost are for the Plexiglas container and the heatpipe cooler. Table 2 provides the amount of salvage value for different parts of the thermoelectric solar still. Table 3 provides the results of cost analysis on thermoelectric solar still supposed that average annual yield of fresh water was 180 L/m^2. Table 4 provides a comparison between the present and other type of solar still reported in literature [18,33]. Results show that this type has a comparable productive cost compare with others.

Table 2
Cost of fabricated solar still in the present work.

Unit	Cost of present solar still $	Salvage value $
Plexiglas container	60	12
Power 12 V	23	5
Heatpipe	70	50
Thermoelectric cooler	9	4
DC fan	15	5
Thermal silicon paste	4	–
Total cost	181	76

7. Conclusion

In this work, a novel portable thermoelectric solar still was designed, fabricated and experimentally tested during five autumn days under the outdoor climatic condition. Based on the results obtained from the experimental work, the following can be concluded:

- The maximum daily efficiency of the still in the period of experiments is 7%
- The daily productivity is directly proportional to solar radiation and ambient temperature, but wind velocity has an inverse effect on productivity
- The temperature of the cold side of thermoelectric module was apparently lower than wall temperature. So by using thermoelectric module, higher temperature difference is achieved
- By combination of heatpipe and thermoelectric cooler, it is possible to increase the productivity of PTSS

The aim of this work was to study the feasibility of using the heatpipe as a cooling device of the thermoelectric modules in the portable solar stills. There are some suggestions for further works in this field:

1. Using the insulated Plexiglas walls around the basin to reduce the water heat loss.
2. Using the double sloped type solar still and eliminating the collecting plate to enhance the motion of humid air around the aluminum plate.
3. Using PCM materials or black Rubbers as heat absorption medium to enhance water production on night.

Table 3
Cost analysis of thermoelectric solar still.

Interest rate %	M L/m^2	CRF	FAC	SSF	ASV	AMC	AC	CPL $/L/m^2
12	180	0.177	32	0.057	4.332	4.8	32.5	0.18

Table 4
Comparison between different type of solar still.

Type	M L/m^2	CPL \$/L/m^2
Pyramid shape	1533	0.031
Sun tracking	250	0.23
Previous work [18]	730	0.13
Single slope	1511	0.035
Transportable hemispherical	1026	0.18
A weir type	1001	0.054
PTSS (this research)	180	0.18

Nomenclature

Q_{ev}	The evaporative heat transfer (W)
$\dot{m}_{ev}$	Distilled water production rate (Kg/s)
A_b	The still base area (m^2)
H	solar radiation fall upon the still and collector surface (W/m^2)
L	The latent heat of the water (J/kg)
CRF	Capital recovery factor
FAC	Fixed annual cost (\$)
SSF	Sinking fund factor
ASV	Annual salvage value (\$)
M	Average annual productivity (L)
AC	Annual cost (\$)
AMC	Annual maintenance operational cost (\$)
CPL	Cost per liter (\$/L)
i	Interest rate (%)
S	Salvage value (\$)
n	life of the system (years)
P	Capital cost (\$)
a	The accuracy of the instrument
u	The standard uncertainty

Greek symbols

η_d	Daily efficiency
η_i	Instantaneous efficiency

Subscripts

b	Basin
d	Daily
i	Instantaneous

Acknowledgments

This work was supported by the Office of the Vice Chancellor for Research, Ferdowsi University of Mashhad, and Grant No. 17291-262/24/12/1389. Also the authors would like to express their grateful thanks to Islamic Azad University, Semnan Branch, for providing information, experimental facilities and their close cooperation.

References

[1] A.E. Kabeel, Performance of solar still with a concave wick evaporation surface, Energy 34 (2009) 1504–1509.
[2] A. Kaushal, Varun, Solar stills: a review, Renewable Sustainable Energy Rev. 14 (2010) 446–453.
[3] M.A. Samee, U.K. Mirza, T. Majeed, N. Ahmad, Design and performance of a simple single basin solar still, Renewable Sustainable Energy Rev. 11 (2007) 543–549.
[4] S.B. Sadineni, R. Hurt, C.K. Halford, R.F. Boehm, Theory and experimental investigation of a weir-type inclined solar still, Energy 33 (Jan 2008) 71–80.
[5] V.K. Dwivedi, G.N. Tiwari, Experimental validation of thermal model of a double slope active solar still under natural circulation mode, Desalination 250 (2010) 49–55.
[6] V. Velmurugan, M. Gopalakrishnan, R. Raghu, K. Srithar, Single basin solar still with fin for enhancing productivity, Energy Convers. Manage. 49 (2008) 2602–2608.
[7] V. Velmurugan, C.K. Deenadayalan, H. Vinod, K. Srithar, Desalination of effluent using fin type solar still, Energy (2008) 1719–1727.
[8] M. Abu-Arabi, Y. Zurigat, H. Al-Hinaib, Modeling and performance analysis of a solar desalination unit with double-glass cover cooling, Desalination 143 (2002) 173–182.
[9] H.M. Ali, Effect of forced convection inside the solar still on heat and mass transfer coefficients, Energy Convers. Manage. 34 (1993) 73–79.
[10] H.M. Ali, Experimental study on air motion effect inside the solar still on still performance, Energy Convers. Manage. 32 (1991) 67–70.
[11] F. Tabrizi, A. Zolfaghari, Experimental study of an integrated basin solar still with a sandy heat reservoir, Desalination 253 (2010) 195–199.
[12] S. Abdallah, O.O. Badran, Sun tracking system for productivity enhancement of solar still, Desalination 220 (2008) 669–676.
[13] P.K. Abdenacer, S. Nafila, Impact of temperature difference (water-solar collector) on solar-still global efficiency, Desalination 209 (Apr 2007) 298–305.
[14] B. Bacha, T. Dammak, B. Abdalah, Desalination unit coupled with solar collectors and a storage tank: modelling and simulation, Desalination 206 (2007) 341–352.
[15] K. Voropoulos, E. Mathioulakis, V. Belessiotis, Solar stills coupled with solar collectors and storage tank—analytical simulation and experimental validation of energy behavior, Sol. energy 75 (2003) 199–205.
[16] S. Kumar, A. Tiwari, An experimental study of hybrid photovoltaic thermal (PV/T)-active solar still, Int. J. Energy Res. 32 (2008) 847–858.
[17] I. Basel, Design and performance of a transportable hemispherical solar still, Renewable Energy 34 (2009) 145–150.
[18] J.A. Esfahani, N. Rahbar, M. Lavvaf, Utilization of thermoelectric cooling in a portable active solar still — an experimental study on winter days, Desalination 269 (2011) 198–205.
[19] R.K. Rajput, Non conventional refrigeration systems, Refrigeration and Air Conditioning, 1st ed, Sanjeev Kumar Kataria, 2005, pp. 328–331.
[20] P.S. Desai, Thermoelectric refrigeration, Refrigeration and Air Conditioning for Engineers, 1st ed, Romesh Chandra Khanna, 2004, pp. 313–322.
[21] S.B. Riffat, X. Ma, Thermoelectrics: a review of present and potential applications, Appl. Therm. Eng. 23 (2003) 913–935.
[22] D. Astrain, J.G. Vián, M. Domínguez, Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation, Appl. Therm. Eng. 23 (2003) 2183–2200.
[23] W. Zheng, G. Xu, Influence of Air Heat Sink Geometry on the Performance of Thermoelectric Cooling Modules, Pasadena, CA, USA, 1996, pp. 311–314.
[24] J.G. Vián, D. Astrain, Development of a thermoelectric refrigerator with two-phase thermosyphons and capillary lift, Appl. Therm. Eng. 29 (2009) 1935–1940.
[25] S.B. Riffat, S.A. Omer, X. Ma, A novel thermoelectric refrigeration system employing heat pipes and a phase change material: an experimental investigation, Renewable Energy 23 (2001) 313–323.
[26] I. Al-Hayek, O.O. Badran, The effect of using different designs of solar stills on water distillation, Desalination 169 (Oct 2004) 121–127.
[27] A.J.N. Khalifa, A.M. Hamood, On the verification of the effect of water depth on the performance of basin type solar stills, Sol. Energy 83 (2009) 1312–1321.
[28] M.K. Phadatare, S.K. Verma, Influence of water depth on internal heat and mass transfer in a plastic solar still, Desalination 217 (2007) 267–275.
[29] G.N. Tiwari, V. Dimri, A. Chel, Parametric study of an active and passive solar distillation system: energy and exergy analysis, Desalination 242 (2009) 1–18.
[30] R. Tripathi, G.N. Tiwari, Thermal modeling of passive and active solar stills for different depths of water by using the concept of solar fraction, Sol. Energy 80 (2006) 956–967.
[31] H.E.S. Fath, M. El-Samanoudy, K. Fahmy, A. Hassabou, Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations, Desalination 159 (2003) 69–79.
[32] S. Kumar, G.N. Tiwari, Life cycle cost analysis of single slope hybrid (PV/T) active solar still, Appl. Energy 86 (2009) 1995–2004.
[33] A.E. Kabeel, A.M. Hamed, S.A. El-Agouz, Cost analysis of different solar still configurations, Energy 35 (2010) 2901–2908.
[34] M.F.A. Goosen, S.S. Sablani, W.H. Shayya, C. Paton, H. Al-Hinai, Thermodynamic and economic considerations in solar desalination, Desalination 129 (Jun 2000) 63–89.
[35] L. Kirkup, R. Frenkel, An Introduction to Uncertainty in Measurement Using the GUM (Guide to the Expression of Uncertainty in Measurement), 1 ed, Cambridge University Press, Cambridge, 2006.
[36] I. Lira, Evaluation the Measurement Uncertainty Fundamental and Practical Guidance, Institute of Physics Publishing, 2002.
[37] N.M. Khattab, E.T. El Shenawy, Optimal operation of thermoelectric cooler driven by solar thermoelectric generator, Energy Convers. Manage. 47 (2006) 407–426.
[38] H. Al-Hinai, M.S. Al-Nassri, B.A. Jubran, Effect of climatic, design and operational parameters on the yield of a simple solar still, Energy Convers. Manage. 43 (Sep 2002) 1639–1650.
[39] V.K. Dwivedi, G.N. Tiwari, Comparison of internal heat transfer coefficients in passive solar stills by different thermal models: an experimental validation, Desalination 246 (2009) 304–318.